



## King County

### Water and Land Resources Division

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## TECHNICAL MEMORANDUM

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TO: Josh Baldi, Division Director, Water and Land Resources (WLR) Division

FM: Jeff Burkey, Hydrologist, Science and Technical Support Section, WLR Division

RE: Updated Estimate of the Annual Average Volume of Treated and Untreated Stormwater Runoff from Developed Lands in King County

## INTRODUCTION

This technical memorandum<sup>1</sup> provides an estimate of the annual average volume of treated<sup>2</sup> and untreated stormwater runoff from developed<sup>3</sup> lands in King County (Figure 1). Methods for calculating these volumes, and a simple sensitivity analysis, are also summarized. Estimated annual average stormwater volumes are presented in Table 1, below.

**Table 1. Annual average stormwater runoff volume (in billions of gallons) from developed lands in King County**

	Area	Treated (% of area total)	Untreated (% of area total)	Total	% of Overall Total
(a)	Seattle	13.9 (67%)	6.8 (33%)	20.7	14%
(b)	Urban outside Seattle	10.1 (14%)	60.1 (86%)	70.1	48%
(c)	All Urban (a+b)	24.0 (26%)	66.9 (74%)	90.8	62%
(d)	Rural	3.1 (6%)	51.7 (94%)	54.9	38%
	All King County (c+d)	27.1 (19%)	118.6 (81%)	145.7	100%

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<sup>1</sup> This technical memorandum is an update to the versions dated in October 2018.

<sup>2</sup> Treated stormwater runoff is runoff that is treated either by stormwater facilities or through the King County Wastewater Treatment collection system.

<sup>3</sup> Developed land is landscape that has been modified from its native vegetative state and presumed to contribute pollutant loadings. Runoff from developed lands does not include, for example, runoff from forested land cover.

## **BACKGROUND**

Stormwater runoff generated from the developed landscape is a ubiquitous problem. For more than a century, development in the Puget Sound region concentrated in the Seattle area and has expanded outward. As the population continues to grow and more land develops, the need to mitigate the stormwater impact increases.

Over the last several decades, resources have been directed to mitigate stormwater impacts from development. In 1990, King County added water quality treatment and substantially improved methodologies for flow control to its stormwater regulations. Water quality treatment is the removal of pollutants from the stormwater that runs off developed land while flow control is the limiting of rate and/or volume of the same stormwater runoff. By the time these mitigations were applied to new development, there were already over 1.5 million people living in King County. This means most of King County has been developed with little or no water quality treatment and flow control. Since 1990, the population has continued to increase nearly 2 percent each year. Development since 1990 has generally included both water quality treatment and substantially improved flow control, with the requirements for both strengthening over time to minimize new impacts and reduce previous impacts. For the purposes of this technical memo, the terms “stormwater treatment” and “treated stormwater” will hereafter mean the application of both water quality treatment and flow control to the runoff from developed land.

## **GOALS & OBJECTIVES**

The goal of this analysis is to estimate the volume of stormwater runoff entering receiving waters (streams, lakes, wetlands, and excluding groundwater) in King County. Awareness of this issue is expected to help the region prioritize how to allocate scarce resources to achieve clean waters and healthy habitat.

There are two objectives for this analysis:

- (1) To quantify how much stormwater runoff to receiving waters is generated from rainfall on the developed landscape within King County under current conditions, and further differentiate between what might be treated versus untreated.
- (2) To document the methods used and allow for an internal and external technical review of the analysis so that it can be understood and refined over time.

## **METHODS**

Estimating the volume of stormwater runoff from developed land countywide was simplified for this cursory level of analysis. The following sections are a summary of the elements that went into the analysis and the results.

## **Flow Pathways**

This analysis assumes that when rain falls on the landscape, it can travel in one of four pathways. It can travel as:

- (1) sheet flow along the surface (**surface flow**),
- (2) infiltration into the soils at a shallow depth, then travel horizontally quickly resurfacing into nearby conveyances such as stormwater networks (**interflow**),
- (3) infiltration into deeper soils generally resurfacing down gradient in streams, lakes, rivers, and wetlands (active **groundwater flow**), or
- (4) Evapotranspiration (i.e., evaporation and/or transpiration) (**ET**).

Stormwater runoff is calculated using (1) + (2) from above. Rainfall that directly infiltrates to the groundwater or cycles back to the atmosphere [(3) + (4)] is not included in the quantity estimate for stormwater runoff.

## **Soil Characteristics**

The proportion of how much runoff flows in a given pathway is determined by how much of the landscape has hardened surfaces and the infiltration capacity of the underlying soils. The less permeable the surface and/or soils, the greater the translation of rainfall into runoff. Rainfall that infiltrates into the deeper soils (i.e., groundwater flow) is not considered as part of the stormwater runoff of interest for this analysis. The soil characteristics for King County were generalized into three classes: *till*—low permeability, *outwash*—high permeability, and *hydric*—saturated conditions. The distribution of these generalized soils in King County are shown in Figure 2.

## **Land Use and Land Cover**

The land use and land cover used for this analysis is National Land Cover Database (NLCD) developed using 2011 satellite imagery. That dataset has the landscape classified into 26 different land use and land cover categories for the King County region (Figure 3). The land use (i.e., developed) categories are presumed to contribute to pollutant loadings and flow impacts, while the land cover categories do not. Thus, only stormwater runoff from the land use categories are part of the calculations quantifying volumes.

The land use categories as described in the National Land Cover Database included in the estimation of stormwater runoff volumes are:

- High intensity developed
- Medium intensity developed
- Low intensity developed
- Developed open space
- Cultivated
- Pasture/Hay
- Grassland

The land cover categories that do not contribute to pollutant loadings and flow impacts are:

- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Scrub/Shrub
- Palustrine Forested Wetland
- Palustrine Scrub/Shrub Wetland
- Palustrine Emergent Wetland
- Estuarine Forested Wetland
- Estuarine Scrub/Shrub Wetland
- Estuarine Emergent Wetland
- Unconsolidated Shore
- Bare Land
- Water
- Palustrine Aquatic Bed
- Estuarine Aquatic Bed
- Tundra
- Snow/Ice

### ***Hydrologic Modeling***

The Hydrologic Simulation Program- FORTRAN (HSPF) was used to quantify stormwater runoff for different combinations of soils, land use, and land cover as previously mentioned. Sixty-one years of hourly Sea-Tac rainfall were used to simulate the flow rates from a unit area of each combination. A mean annual flowrate was calculated for each combination so it could be used to scale up countywide.

### ***Rainfall***

Annual rainfall volumes generally increase from west to east because of the orographic effect the Cascade mountain range has on atmospheric conditions. Oregon State University provides spatially distributed rainfall estimates for the continental United States. Using their estimates of mean annual rainfall volumes, the mean annual rainfall ranges from 33 inches in the downtown Seattle area to 173 inches in the Cascade Mountains (Figure 4). This distribution of rainfall was then used to scale up unit area runoff based on the combinations of land use and soils in the county.

### ***Stormwater Treatment***

Stormwater runoff from developed land is either assumed to be treated or untreated. In King County, stormwater treatment did not become a requirement until 1990 when King County

updated its Surface Water Design Manual. Furthermore, cities, other than Seattle, were not required to treat stormwater until 2007; although a number of jurisdictions did have stormwater management and treatment programs prior to being issued their NPDES (National Pollutant Discharge Elimination System) permits. For this analysis, if a parcel was *built* by 1995 or earlier, then it was assumed runoff from that parcel would be untreated (Figure 5).

### **WTD Service Area Estimates**

King County Wastewater Treatment Division (WTD) provided volumetric estimates of treated and untreated effluent in their combined stormwater-sewer network<sup>4</sup> (Figure 6). There are three possible outcomes when stormwater enters into the WTD combined sewer system.

- (1) Stormwater and sewage receives secondary treatment at a regional treatment plant,
- (2) Capacity has been exceeded in part of the system, but receives primary treatment through a CSO wet weather treatment station, or
- (3) Capacity has been exceeded, and discharges through outfalls as untreated stormwater and sewage.

For the collection areas within the WTD service area (Figure 7), it is estimated that, on average, a total of 593 million gallons of untreated stormwater (527.6 million gallons from King County CSOs and 65.4 million gallons from City of Seattle CSOs) discharges into open bodies of water. This estimate includes a portion, but not all of City of Seattle's CSO discharges.

Two scenarios were evaluated for estimated discharges of untreated stormwater through CSOs: (1) Existing conditions and (2) Future conditions. Existing conditions represents the existing infrastructure that is online. Future conditions represents all CSO projects are completed, but with existing land use and populations.

The list of CSO areas for WTD and SPU facilities included in the computations are shown in Table 2 and 3 below. The detailed list of individual CSOs are found in Table 7 and 8 near the end of this document.

**Table 2. List of King County CSO areas included in the analyses and estimated average annual discharges in millions of gallons.**

King County CSO Areas	Existing (MGs)	Future (MGs)
Alki	5.50	5.33
CHLKK	329.77	10.82
Denny/Interbay	5.30	4.16
Georgetown	77.46	3.15
Henderson	0.03	0.03
North	75.79	24.26

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<sup>4</sup> King County's defined combined stormwater network is different than Seattle's defined system.

Rainier	2.01	2.01
Ship Canal Project	29.02	5.11
West Duwamish	2.79	1.88
<b>Total</b>	<b>527.67</b>	<b>56.75</b>

**Table 3. List of City of Seattle CSO areas included in the analyses and estimated average annual discharges in millions of gallons. These estimates do not include all of Seattle's CSOs.**

City of Seattle CSO Areas	Existing (MGs)	Future (MGs)
Along EBI	2.46	0.71
Delridge	1.98	1.69
Genesee	3.33	1.93
Henderson	4.58	3.86
Leschi	0.58	0.47
Ship Canal Project	50.35	2.96
Windermere/NUB	2.17	2.13
<b>Total</b>	<b>65.45</b>	<b>13.76</b>

Treated stormwater collected in the WTD service area including City of Seattle (SPU) totals on average 12.4 billion gallons annually for existing conditions. Future conditions with all CSO projects completed, the treatment volumes increase to 12.9 billion gallons (see Table 4).

**Table 4. Estimates for WTD combined collection service area. Values in [ ] reflect estimates for a portion of the Seattle CSOs, but not all of them.**

Time Period	Stormwater in Combined System	Existing Conditions (billions gallons)	Georgetown and Ship Canal Completed (billions gallons)	All CSO Projects Completed (billions gallons)
Long-term average*	Treated	12.41	12.55	12.93
	Untreated	.593 [.065]	.447 [.018]	.070 [.013]

\*Simulation is from 1/2/1978 – 12/31/2015

## ***King County Stormwater Runoff Volume Estimates***

Unit area stormwater runoff was estimated using watershed modeling software that takes into account land use, land cover, local geologic conditions, and rainfall patterns. Summing up stormwater runoff only from those land uses specified above and only runoff from surface and interflow pathways, the total estimated stormwater runoff per year is 145.7 billion gallons for King County. This includes all contributions from WTD collection area. Thus, subtracting out WTD contributions, the total stormwater runoff from developed land is 132.7 billion gallons. Using the age of development to determine if stormwater runoff is treated or not (excluding

WTD collection area in combined system), the amount of untreated stormwater runoff from developed land totals 118.0 billion gallons and treated is about one-eighth of that at 14.7 billion gallons annually. See Figure 8 for illustration of breakdown.

### ***Integrating WTD Estimates into County Wide***

Using the age of development within the combined stormwater system within the City of Seattle as the determining factor of treated versus untreated estimates a 1.5 billion gallons treated and 19.2 billion gallons untreated. However, this method breaks down considering the combined stormwater system is independent of age of development of the parcel. In addition, the combined stormwater service area nearly completely resides within the City of Seattle (Figure 6). Thus, WTD model estimates of volume treated (12.4 billion gallons) is added to the 1.5 billion gallons. This addition to treated volumes is then subtracted from untreated volumes to maintain mass balance of overall rainfall on the landscape. It should be mentioned, that there may be some fraction of double counting because part of the 1.5 billion that is treated on the surface may still make it into the combined system.

## ASSUMPTIONS AND DATA USED

Calculating stormwater runoff is based on the characterization of the landscape into numerous elements that each influence the path rain takes once falling on the ground. The elements used in this analysis are:

- land cover,
- generalized soil characteristics,
- rainfall amounts, and
- age of development.

The types of tools used include: GIS, spreadsheets, and hydrologic modeling.

### **GIS Data**

GIS data used include:

- National Land Cover Database (NLCD) – 2011 Satellite imagery classified into 26 land use categories at a grid scale of 30-meters (Figure 3).
- NLCD Percent Impervious – 2011 Land cover data quantifying the fraction of a grid cell considered to be an impervious surface (Figure 9).
- United States Geological Survey Geology (USGS) – Surficial geology generalized into three types of soils: (1) *Till* – low infiltration, (2) *Outwash*- high infiltration, and (3) *Hydric*- saturated soils (Figure 2).
- Oregon State University, PRISM Climate Group (PRISM-OSU) – Spatially distributed mean annual rainfall (1981–2010) at a grid scale of 800-meters (Figure 4).
- King County Roads – A linear feature dataset showing alignment for road right-of-ways.
- King County Impervious Surfaces – A high resolution dataset characterizing impervious surfaces on the landscape (Figure 10).
- King County Assessor's Office – The attribute specifying when a particular parcel was developed. Four files were needed for this:
  - Residential Building (resbldg\_extr)
  - Apartment Complexes (aptcomplex\_extr)
  - Condos (condocomplex\_extr)
  - Commercial Building (commbldg\_extr)

### **Hydrologic Modeling**

The hydrologic model used for assessment is based on Hydrologic Simulation Program – FORTRAN (HSPF). This is a U.S. EPA modeling platform that allows for evaluating numerous environmental conditions including stormwater runoff. HSPF has been used in the Puget Sound region starting in the 1980s and has continued to be the dominant watershed modeling software package for multiple regulating agencies and local jurisdictions.

Application of HSPF watershed modeling countywide may be accomplished in multiple ways and can be as simple or complex as desired. Regional HSPF parameters established back in 1990s and updated in the 2000s were used for this effort at this point. The parameters used for HSPF modeling are the same parameters used as part of the Washington State Department of Ecology stormwater design software Western Washington Hydrologic Modeling 2012 (WWHM2012). See Table 5.

The simplification in HSPF model development included the following presumptions:

- Soil types were generalized into three categories (Figure 2):
  - (1) *till* – low infiltration,
  - (2) *outwash* – high infiltration, and
  - (3) *hydric* – saturated soils.
- All developed areas were assumed to be very low gradient (i.e., *flat*).
- One rainfall observation station (National Weather Service, Sea-Tac) was used for simulation.
- One evapotranspiration monitoring station (WSU, Puyallup) of data was used for simulation.
- Land uses that are considered developed categories are (Figure 3):
  - High intensity developed
  - Medium intensity developed
  - Low intensity developed
  - Developed open space
  - Cultivated
  - Pasture/Hay
  - Grassland
- Only runoff from developed land cover were partitioned into either impervious, and/or grass, and/or pasture (Table 6).
- Road surfaces that also intersect non-developed land cover are also included and are reflected as a non-zero values in the land use partitioning; for example, logging roads through forested landscape (Table 6 and Figure 11).
- Simulation time period was from October 1, 1948, through September 30, 2009.

The various land use and land cover categories are reduced into relevant hydrologic response units (HRUs) that are defined in watershed models. HRUs are typically combinations of soil, land cover, land use, and topographic slope, but can be more complex or simpler if needed. For simplicity in this analysis, slope was not included and hydrologic parameters associated with flat slopes were employed.

Simulated unit area runoff (i.e., surface runoff + interflow) converted to inches per unit area (i.e., acres) using Sea-Tac rainfall were generated for the following soil-land cover-slope combinations (Figure 12):

- Outwash Pasture Flat (OPF), 0.019 inches per acre
- Outwash Grass Flat (OGF), 0.080 inches per acre
- Till Pasture Flat (TPF), 8.79 inches per acre
- Till Grass Flat (TGF), 12.91 inches per acre
- Impervious (EIA), 31.03 inches per acre

Thus by intersecting the GIS data layers (USGS Soils + NLCD 2011), the distributions defined in Table 6 can then be applied to generate runoff at a unit area, then scaled countywide.

### ***Rainfall Scaling***

King County spans from the Puget Sound to the crest of the Cascades. Annual rainfall volumes generally increase from west to east due mainly to the orographic effects of the Cascade mountain range (see Figure 4). A National Weather Service monitoring station located at Sea-Tac International Airport is commonly used as the official record of rainfall in the greater Seattle area. As previously mentioned, data from this station was used as input for the watershed modeling.

A scalar was applied to the unit area runoff values based on the relative magnitude of PRISM estimates to the historical average at Sea-Tac (38.08 inches). Runoff generally does not respond linear in nature, but for this level of analysis a simplified linear relationship was used.

### ***Stormwater Treatment***

The analysis considers that flow control and water quality treatment became part of King County's stormwater design standards in 1990 and have been updated through the years—the most recent update in 2016. The first Municipal National Pollutant Discharge Elimination System (NDPES) Stormwater permit was issued to King County in 1995, the NPDES permit for smaller jurisdictions to implement water quality treatment was not issued until 2007.

The process of when a parcel gets developed starts with a permit application. The time between when the permit application is started and completion of construction can be many years, although a recent state Supreme Court action has ended this practice. The prior requirements applied to the development generally were based on when the permit application was started, not when construction is completed. The determination of whether stormwater runoff is treated or untreated was based on the year when a particular parcel of land was developed.

The “year built” in the King County Assessor's database is based on completion of construction. Based on this aspect in addition to the lag between permit and construction, it was decided to use 1995 as the year to determine if the developed parcel of land received treatment or not. This was assumed countywide including all jurisdictions (see Figure 5). Additional assumptions defining treated versus untreated are as follows:

- Although some roads have been retrofitted with treatment, the inventory is small so the assumption used is that all roads are untreated

- Any parcel of land that had no “year built” value assigned, but was classified as one of the developed land use categories, was assumed untreated.
- Any land use not considered developed (i.e., land cover; see page 4 for list) is considered to generate runoff characteristic of natural conditions. Consequently, runoff from these land cover categories is not included in the stormwater runoff volume calculations.

## **SENSITIVITY ANALYSIS**

There are a lot of assumptions and simplifications used to estimate the amount of countywide stormwater runoff. Thus it is prudent to perform some sensitivity analyses on some of those assumptions. Below are several scenarios designed to test sensitivity in results when changing some of the assumptions and methodologies used. WTD service area contributions are not subtracted from any of the results below.

Best estimate from above:

Result: 145.7 billion gallons

### **Scenario 1: Use alternative method**

Use National Land Cover Database Percent Impervious Surface and apply PRISM rainfall to generate mean annual runoff volumes (see Figure 13).

Result: 147.18 billion gallons

### **Scenario 2: Test assumption of impervious surface effectiveness**

Reduce watershed model generated unit area effectiveness of impervious surfaces underlain with outwash soils by 50% and substitute with grass.

Result: 134.68 billion gallons

### **Scenario 3: Test sensitivity of scaling rainfall**

Using watershed model generated unit runoff, apply no scaling of rainfall (i.e., use 38.08 inches countywide).

Result: 118.62 billion gallons

### **Scenario 4: Test assumption of impervious surface effectiveness countywide**

Reduce watershed model generated unit area effectiveness of all impervious surfaces by 50% (i.e., reduce EIA by 50% and substitute with Grass runoff).

Result: 115.36 billion gallons

**Scenario 5:** Test sensitivity of simplifying slope

Use moderate slope watershed modeling parameters instead of flat slope values.

Result: 150.70 billion gallons

**Scenario 6:** Use alternative method

Use King County impervious surfaces, apply effectiveness based on watershed modeling of 81.5% and apply PRISM rainfall (see Figure 14).

Result: 272.65 billion gallons

**Scenario 7:** Use alternative method and test sensitivity of rainfall scaling

Use King County impervious surfaces, apply effectiveness based on watershed modeling of 81.5% and do not scale rainfall (i.e., use 38.08 countywide).

Result: 212.98 billion gallons

**Scenario 8:** Applying methodology to WTD Service area

The method used in this study was applied to WTD's model basins. The defined fractions of connected impervious and pervious that are part of WTD model parameters are accounted for in this scenario (see Figure 6). As previously provided, the total stormwater volumes collected in the WTD service area is 13.00 billion gallons.

Result: 9.89 billion gallons.

**Scenario 9:** Same as #8, but testing sensitivity of fraction of connection in basins.

Same as Scenario 8, but assuming the entire WTD model basin is 100% connected to the collection network.

Results: 16.28 billion gallons

## CONCLUSIONS

After reviewing the outcomes from the scenarios evaluated above, the consistent result is the relative magnitude of estimated untreated stormwater runoff. The estimated average amount of annual stormwater runoff (treated and untreated) from developed land is at least in the 100 billion gallon range. The estimated amount of treated stormwater runoff is about one-fifth less overall (i.e., 20 billion gallons range). The volume of treated and untreated stormwater runoff compared to the combined sewer-storm contributions is approximately an order of magnitude more; meaning, the contributions from wastewater facilities, treated and untreated, on average is 13.0 billion gallons, or about  $1/10^{\text{th}}$  of the total stormwater runoff.

However, the relative amount of any particular pollutant and its pathway of treated and untreated by stormwater facilities, wastewater facilities, and combinations of stormwater and wastewater infrastructure is not quantified as part of this study. The results may be quite different than the quantitative analysis done here on flow volumes.

The methods used to quantify the runoff are simple by design and are meant to provide an awareness on the orders of magnitude and not necessarily on the specific numbers provided. When and if there is a need to refine the estimates, more effort would be necessary improving assumptions and techniques used converting rainfall into runoff, the amount of treated runoff, and the conveyance to receiving bodies of water.

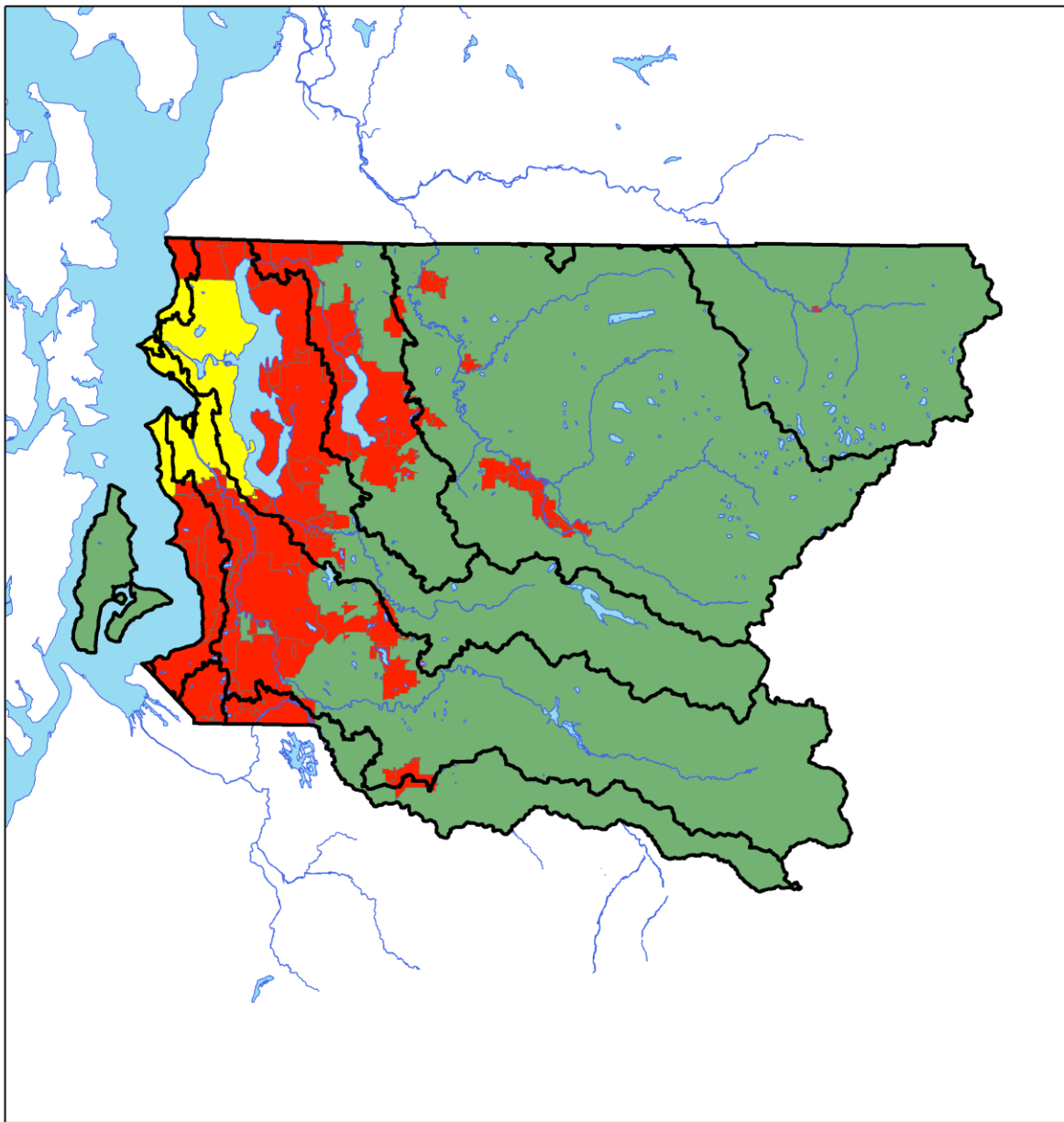
**Table 5.    WWHM2012 (HSPF) HRU Regional Parameters (yellow highlight are parameter sets used for this analysis).**

Symbol	Description	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC	INFEXP	INFILD	AGWETP	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
OFF	Outwash Forest Flat	5	2	400	0.05	0.3	0.996	2	2	0	0.2	0.5	0.35	0	0.7	0.7
OFM	Outwash Forest Moderate	5	2	400	0.1	0.3	0.996	2	2	0	0.2	0.5	0.35	0	0.7	0.7
OFS	Outwash Forest Steep	5	2	400	0.15	0.3	0.996	2	2	0	0.2	0.5	0.35	0	0.7	0.7
OPF	Outwash Pasture Flat	5	1.5	400	0.05	0.3	0.996	2	2	0	0.15	0.5	0.3	0	0.7	0.4
OPM	Outwash Pasture Moderate	5	1.5	400	0.1	0.3	0.996	2	2	0	0.15	0.5	0.3	0	0.7	0.4
OPS	Outwash Pasture Steep	5	1.5	400	0.15	0.3	0.996	2	2	0	0.15	0.5	0.3	0	0.7	0.4
OGF	Outwash Grass Flat	5	0.8	400	0.05	0.3	0.996	2	2	0	0.1	0.5	0.25	0	0.7	0.25
OGM	Outwash Grass Moderate	5	0.8	400	0.1	0.3	0.996	2	2	0	0.1	0.5	0.25	0	0.7	0.25
OGS	Outwash Grass Steep	5	0.8	400	0.15	0.3	0.996	2	2	0	0.1	0.5	0.25	0	0.7	0.25
TFF	Till Forest Flat	4.5	0.08	400	0.05	0.5	0.996	2	2	0	0.2	0.5	0.35	6	0.5	0.7
TFM	Till Forest Moderate	4.5	0.08	400	0.1	0.5	0.996	2	2	0	0.2	0.5	0.35	6	0.5	0.7
TFS	Till Forest Steep	4.5	0.08	400	0.15	0.5	0.996	2	2	0	0.2	0.3	0.35	6	0.3	0.7
TPF	Till Pasture Flat	4.5	0.06	400	0.05	0.5	0.996	2	2	0	0.15	0.4	0.3	6	0.5	0.4
TPM	Till Pasture Moderate	4.5	0.06	400	0.1	0.5	0.996	2	2	0	0.15	0.4	0.3	6	0.5	0.4
TPS	Till Pasture Steep	4.5	0.06	400	0.15	0.5	0.996	2	2	0	0.15	0.25	0.3	6	0.3	0.4
TGF	Till Grass Flat	4.5	0.03	400	0.05	0.5	0.996	2	2	0	0.1	0.25	0.25	6	0.5	0.25
TGM	Till Grass Moderate	4.5	0.03	400	0.1	0.5	0.996	2	2	0	0.1	0.25	0.25	6	0.5	0.25
TGS	Till Grass Steep	4.5	0.03	400	0.15	0.5	0.996	2	2	0	0.1	0.15	0.25	6	0.3	0.25
HFF	Hydric Forest Flat	4	2	100	0.001	0.5	0.996	10	2	0.7	0.2	3	0.5	1	0.7	0.8
HFM	Hydric Forest Moderate	4	2	100	0.01	0.5	0.996	10	2	0.7	0.2	3	0.5	1	0.7	0.8
HFS	Hydric Forest Steep	4	2	100	0.1	0.5	0.996	10	2	0.7	0.2	3	0.5	1	0.7	0.8
HPF	Hydric Pasture Flat	4	1.8	100	0.001	0.5	0.996	10	2	0.5	0.15	3	0.5	1	0.7	0.6
HPM	Hydric Pasture Moderate	4	1.8	100	0.01	0.5	0.996	10	2	0.5	0.15	3	0.5	1	0.7	0.6
HPS	Hydric Pasture Steep	4	1.8	100	0.1	0.5	0.996	10	2	0.5	0.15	3	0.5	1	0.7	0.6
HGF	Hydric Grass Flat	4	1	100	0.001	0.5	0.996	10	2	0.35	0.1	3	0.5	1	0.7	0.4
HGM	Hydric Grass Moderate	4	1	100	0.01	0.5	0.996	10	2	0.35	0.1	3	0.5	1	0.7	0.4
HGS	Hydric Grass Steep	4	1	100	0.1	0.5	0.996	10	2	0.35	0.1	3	0.5	1	0.7	0.4

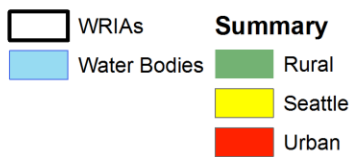
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**Table 6. Land use partitioning into land cover. Land use sols are either till or outwash, not both.**

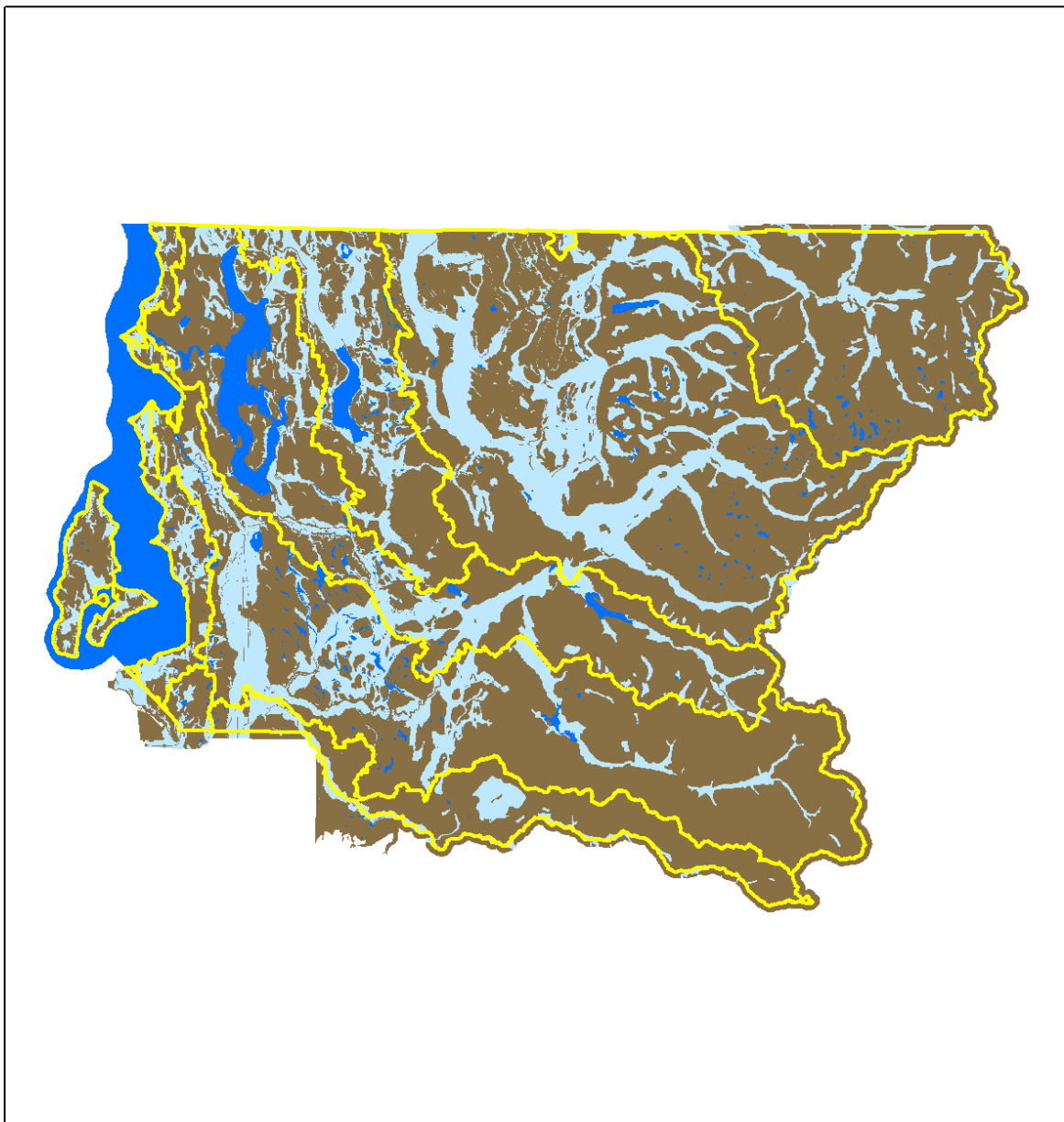
VALUE	CLASS_NAME	TPF	TGF	OPF	OGF	Impervious
1	Unclassified	0	0	0	0	0
2	High Intensity Developed	0	0.19	0	0.19	0.81
3	Medium Intensity Developed	0	0.65	0	0.65	0.35
4	Low Intensity Developed	0	0.94	0	0.94	0.06
5	Developed Open Space	0	0.95	0	0.95	0.05
6	Cultivated	0.9661	0	0.9661	0	0.033901
7	Pasture/Hay	0.9831	0	0.9831	0	0.016919
8	Grassland	0	0.9879	0	0.9879	0.012104
9	Deciduous Forest	0	0	0	0	0.010374
10	Evergreen Forest	0	0	0	0	0.001647
11	Mixed Forest	0	0	0	0	0.006478
12	Scrub/Shrub	0	0	0	0	0.003271
13	Palustrine Forested Wetland	0	0	0	0	0.005049
14	Palustrine Scrub/Shrub Wetland	0	0	0	0	0.004523
15	Palustrine Emergent Wetland	0	0	0	0	0.003883
16	Estuarine Forested Wetland	0	0	0	0	0.00474
17	Estuarine Scrub/Shrub Wetland	0	0	0	0	0.003871
18	Estuarine Emergent Wetland	0	0	0	0	0.003027
19	Unconsolidated Shore	0	0	0	0	0.001562
20	Bare Land	0	0	0	0	0.001395
21	Water	0	0	0	0	7.49E-05
22	Palustrine Aquatic Bed	0	0	0	0	0.001339
23	Estuarine Aquatic Bed	0	0	0	0	0.001848
24	Tundra	0	0	0	0	0.002129
25	Snow/Ice	0	0	0	0	0.001051



**Legend**






**Figure 1. Map of Seattle, Urban, and Rural areas in King County.**



**Legend**

 WRIs **USGS Soils**

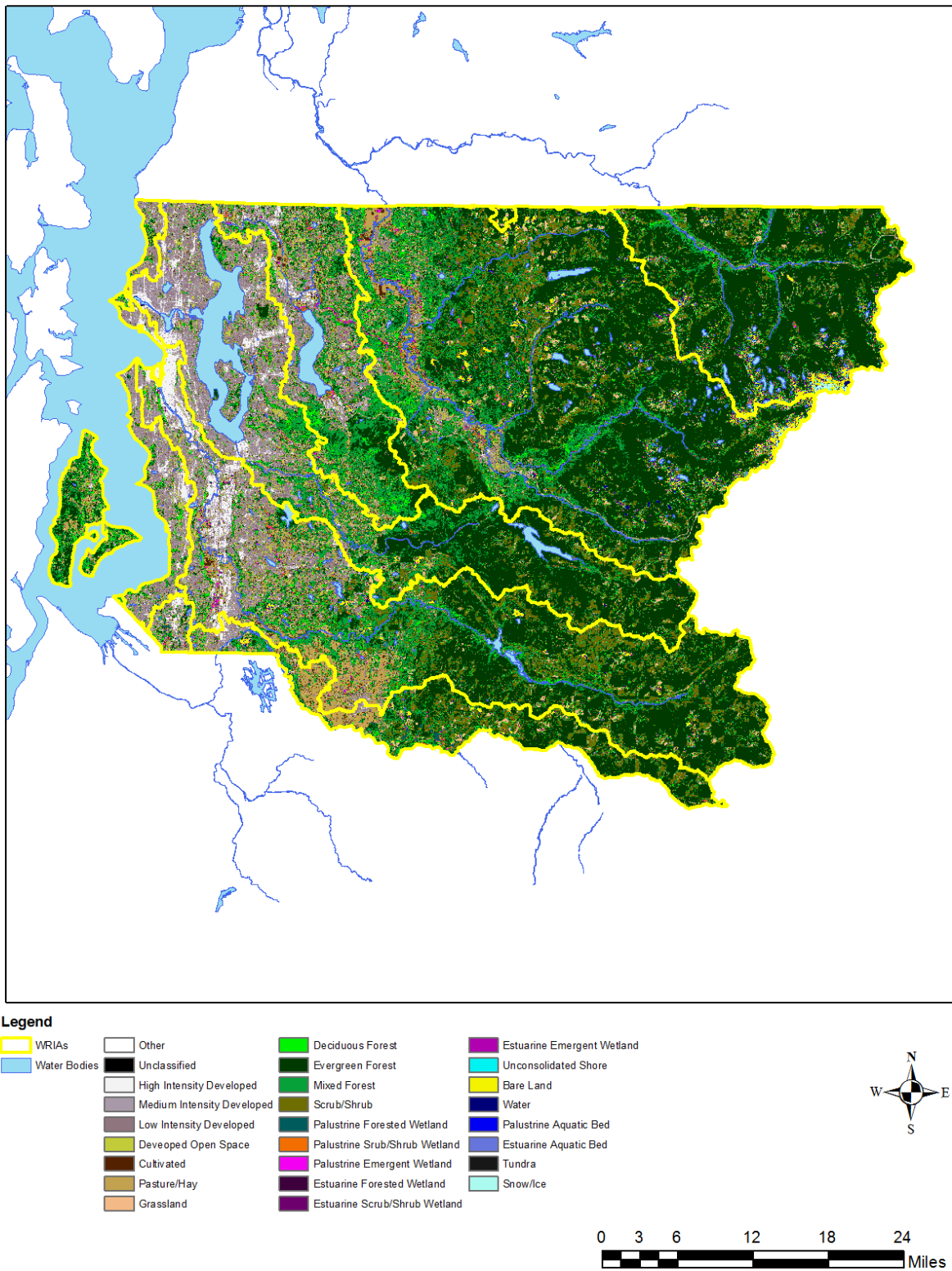
**Soil Type**

 HYDRIC  
 OUTWASH  
 TILL

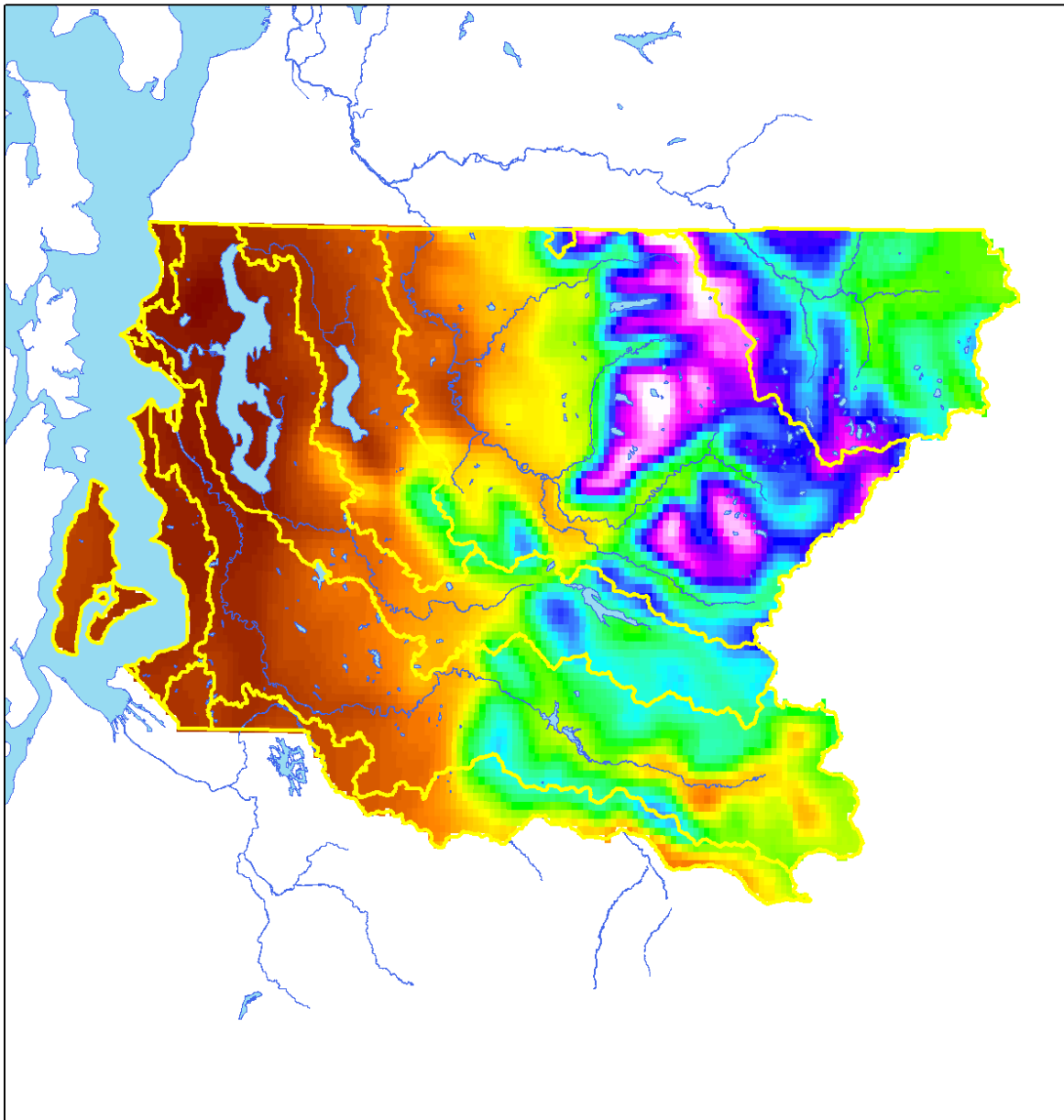


0 3 6 12 18 24  
 Miles

**Figure 2. Map of generalized geology.**



**Figure 3. National Land Cover Database (2011).**



**Legend**

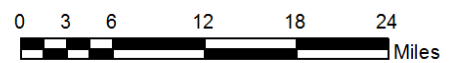
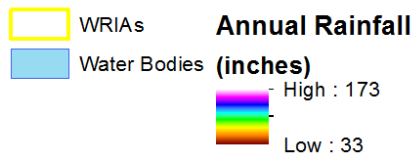
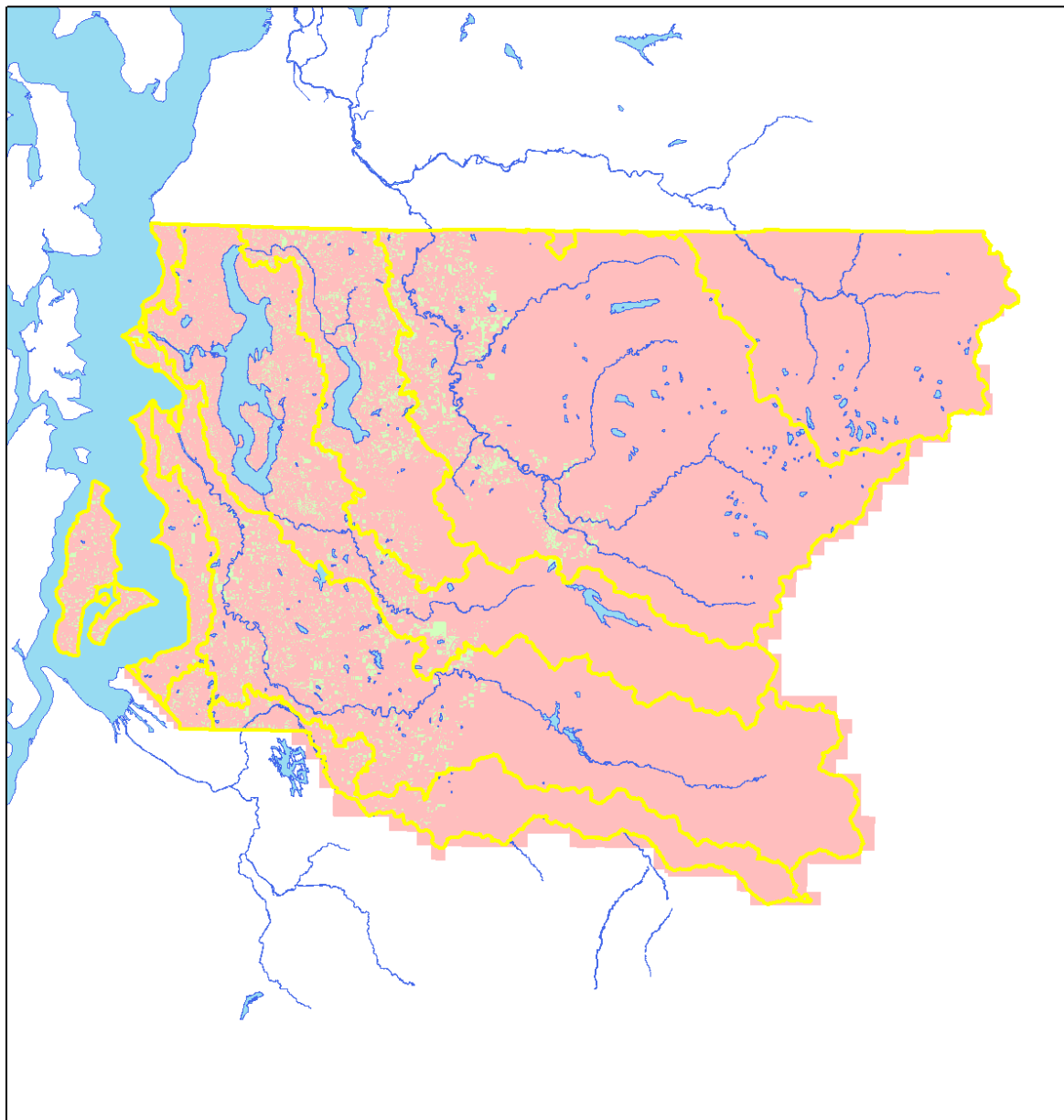






Figure 4. Mean Annual Rainfall for King County (PRISM Climate Group, 2013, <http://prism.oregonstate.edu>)

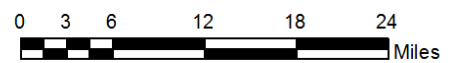


**Legend**

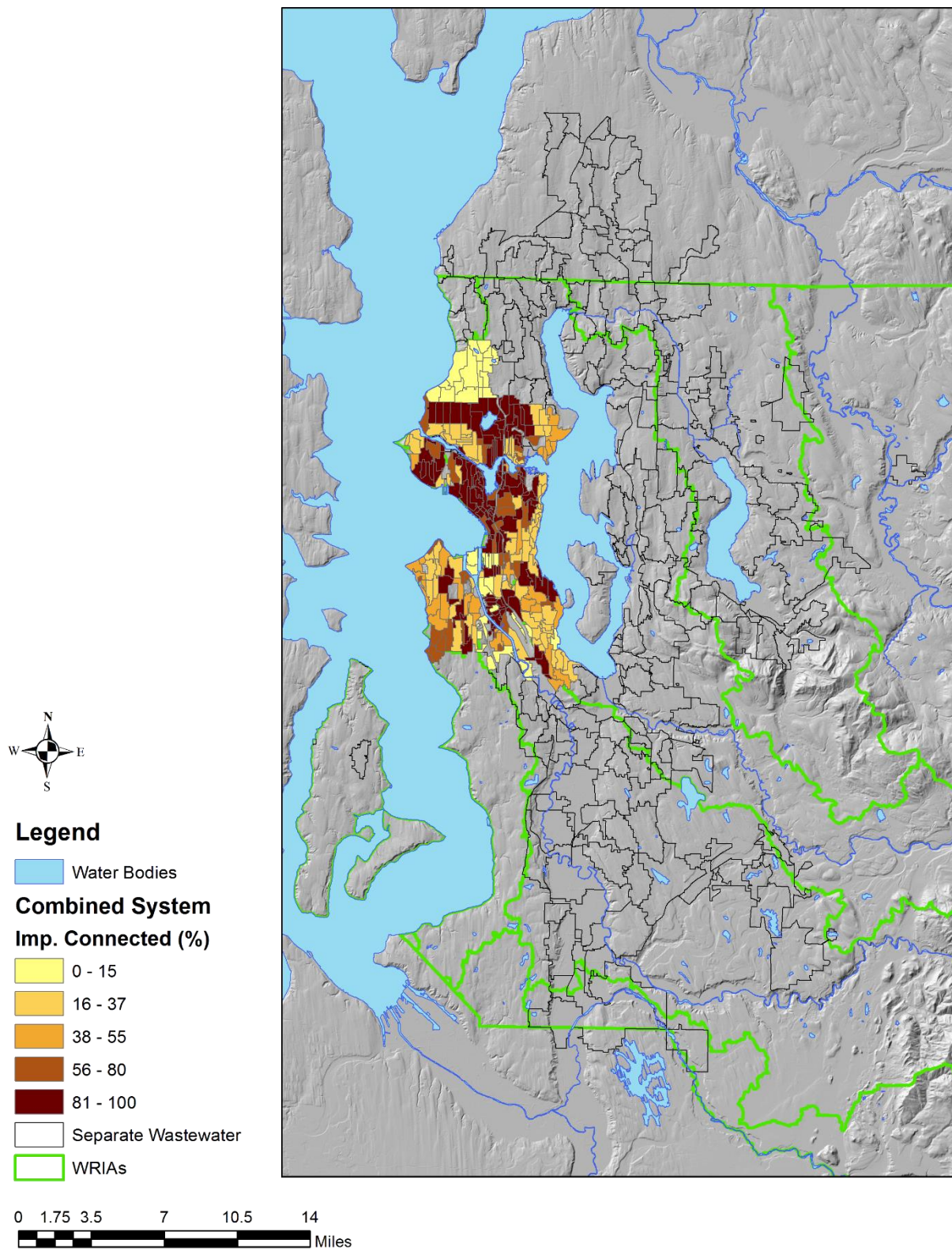
-  WRIs
-  Water Bodies

**Treated  
Category**

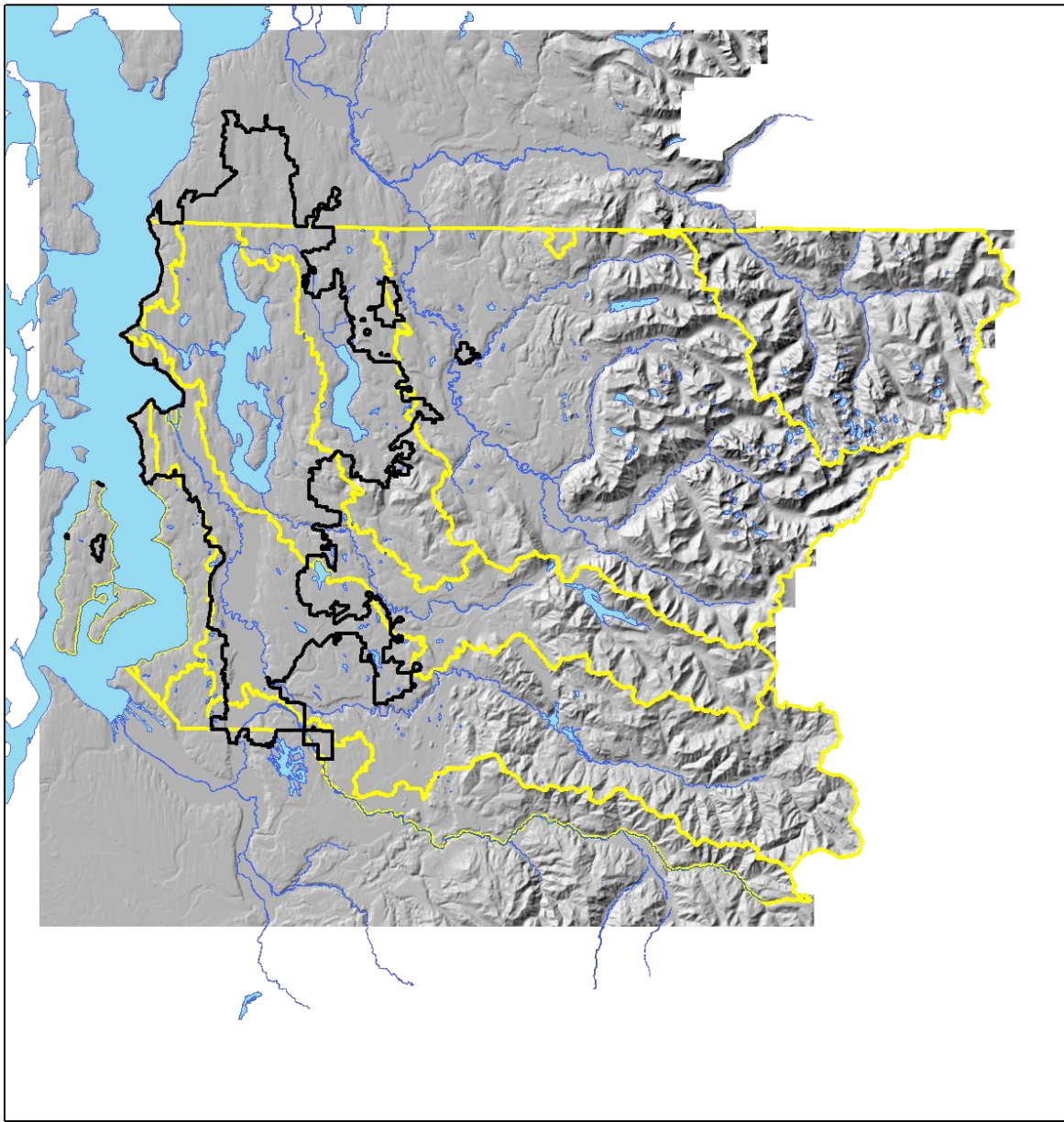
-  Untreated ( $\leq 1995$ )
-  Treated ( $> 1995$ )






**Figure 5.** Map illustrating which parcels were developed before and after 1995.

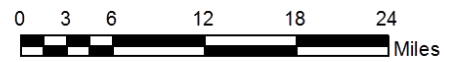


**Figure 6. Map of WTD basins and fraction of connected impervious areas in combined stormwater-sewer service areas.**

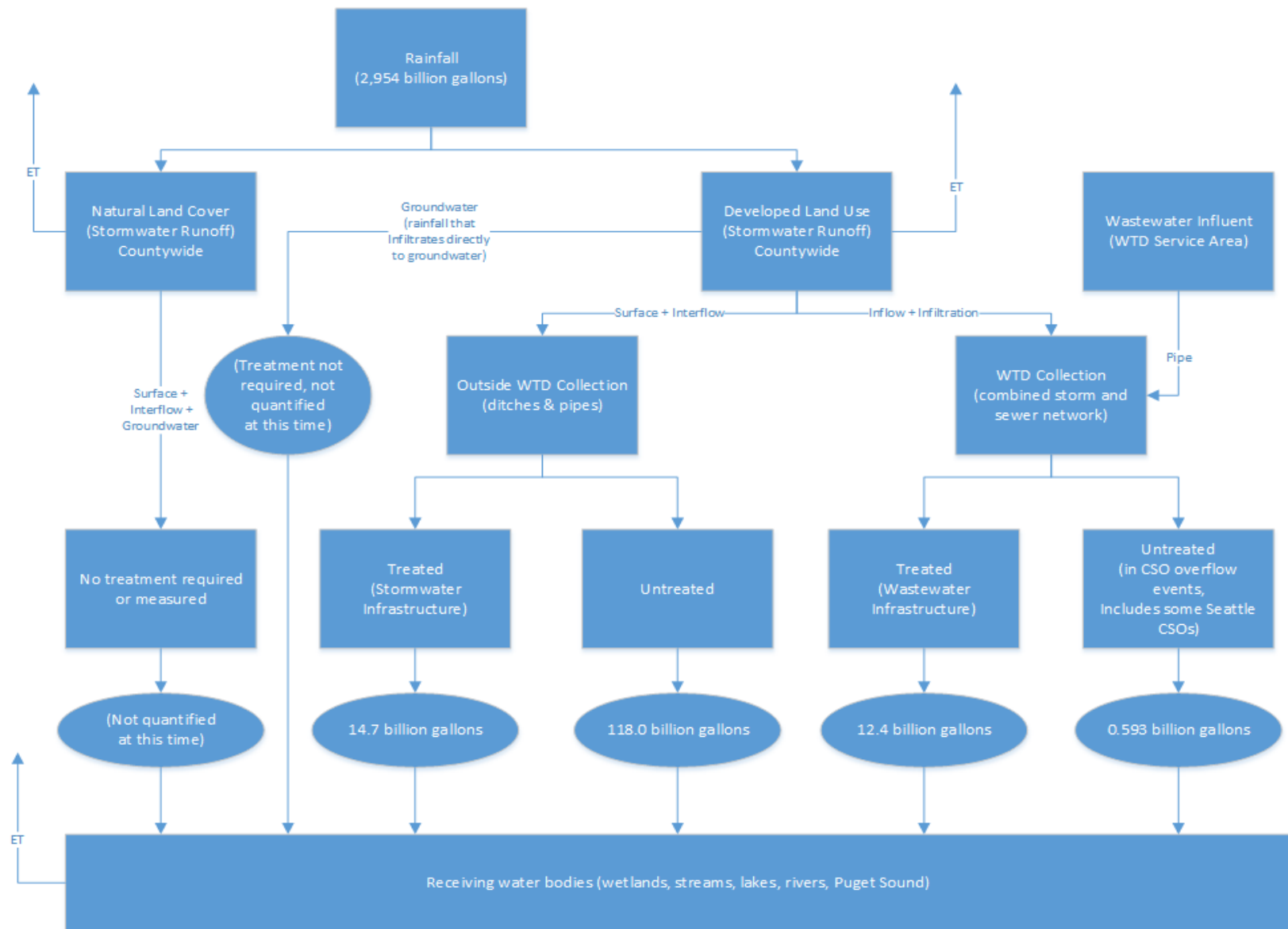


**Legend**

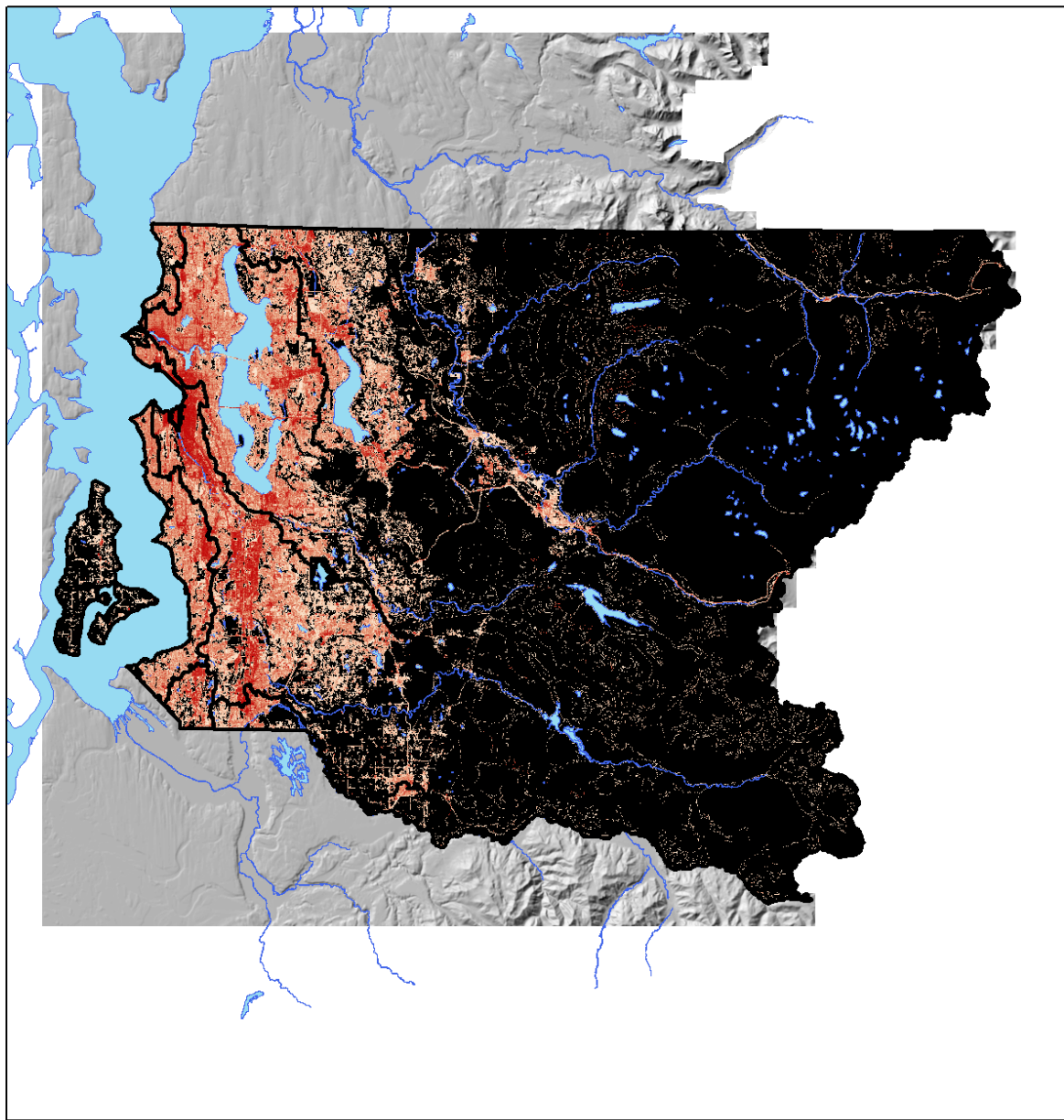
-  WTD Service Area
-  WRIs
-  Water Bodies



**Figure 7. Map of Wastewater Treatment Division Service Area.**




**Figure 8.** Flow chart illustrating the simplified universe of rainfall and runoff for this analysis. Note that runoff from natural land cover and rainfall that directly infiltrates to groundwater is not quantified at this time.




**Legend**

 WRIAs


**NLCD % Impervious**

 High : 100

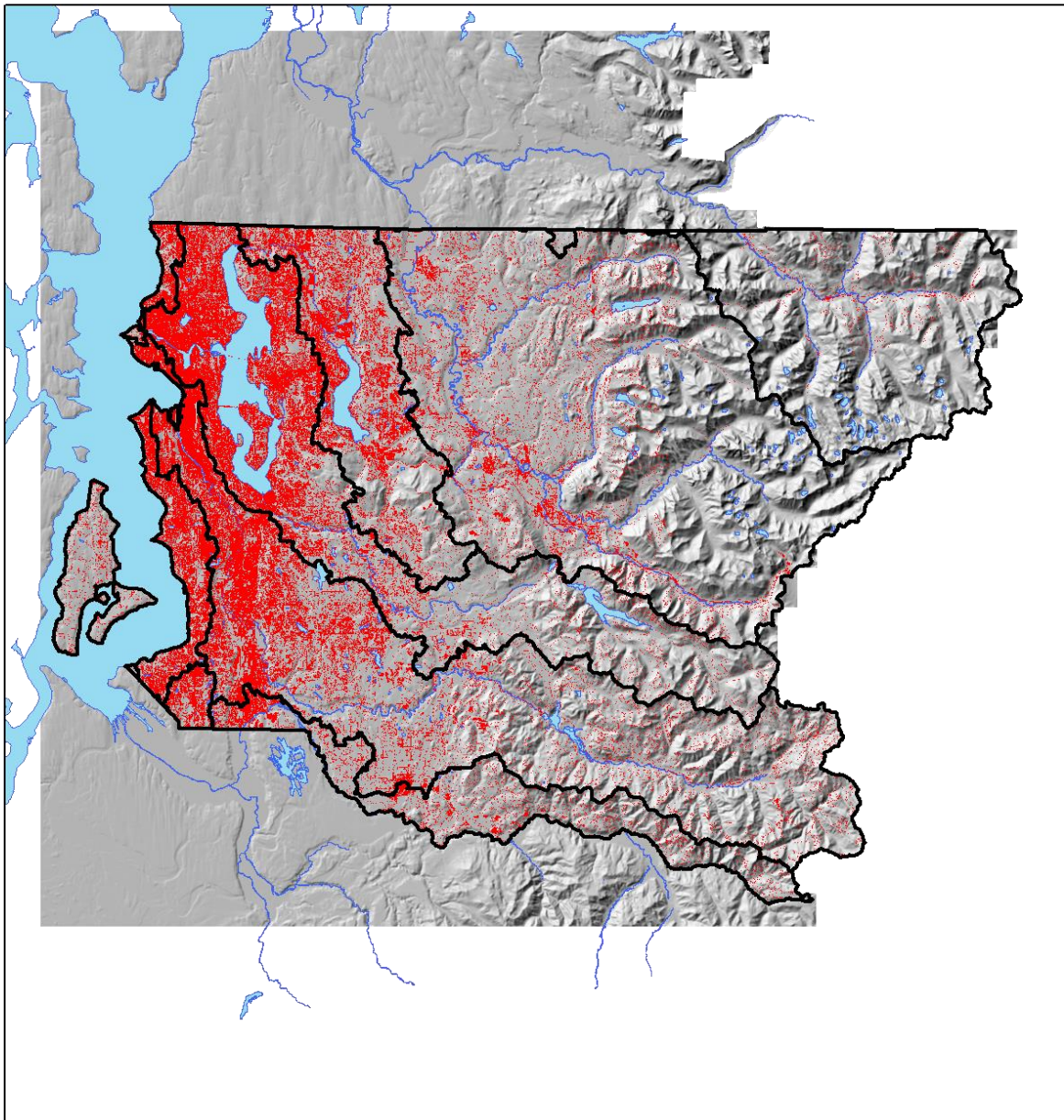
 Low : 1

 Water Bodies



0 3 6 12 18 24  
 Miles


**Figure 9. Map of NLCD (2011) Percent Impervious.**




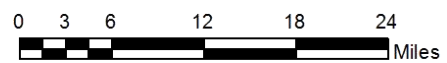
**Legend**

 WRIAs

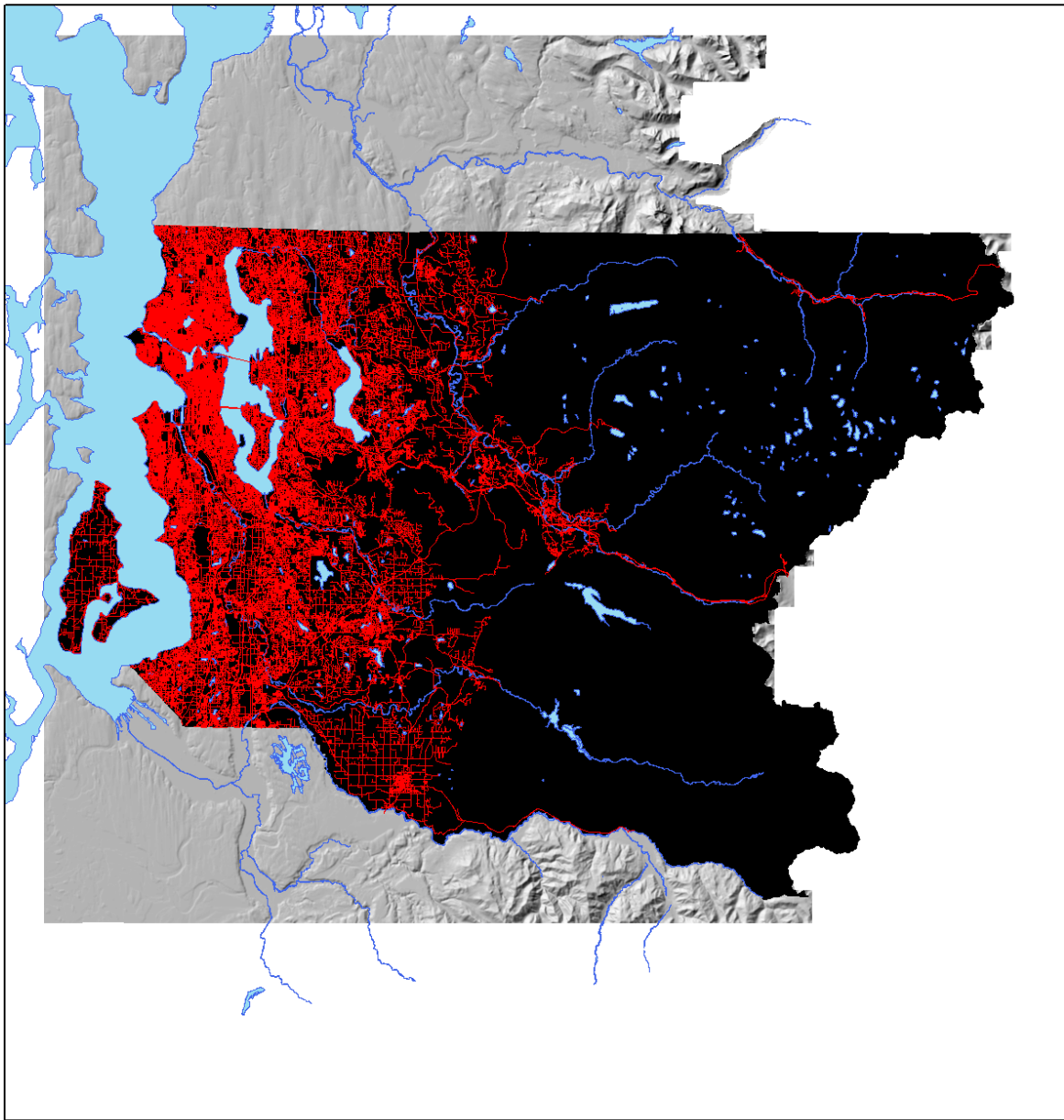
**Land Cover**

 Impervious

 Water Bodies

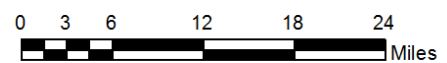


**Figure 10. Map of King County Impervious Surfaces.**

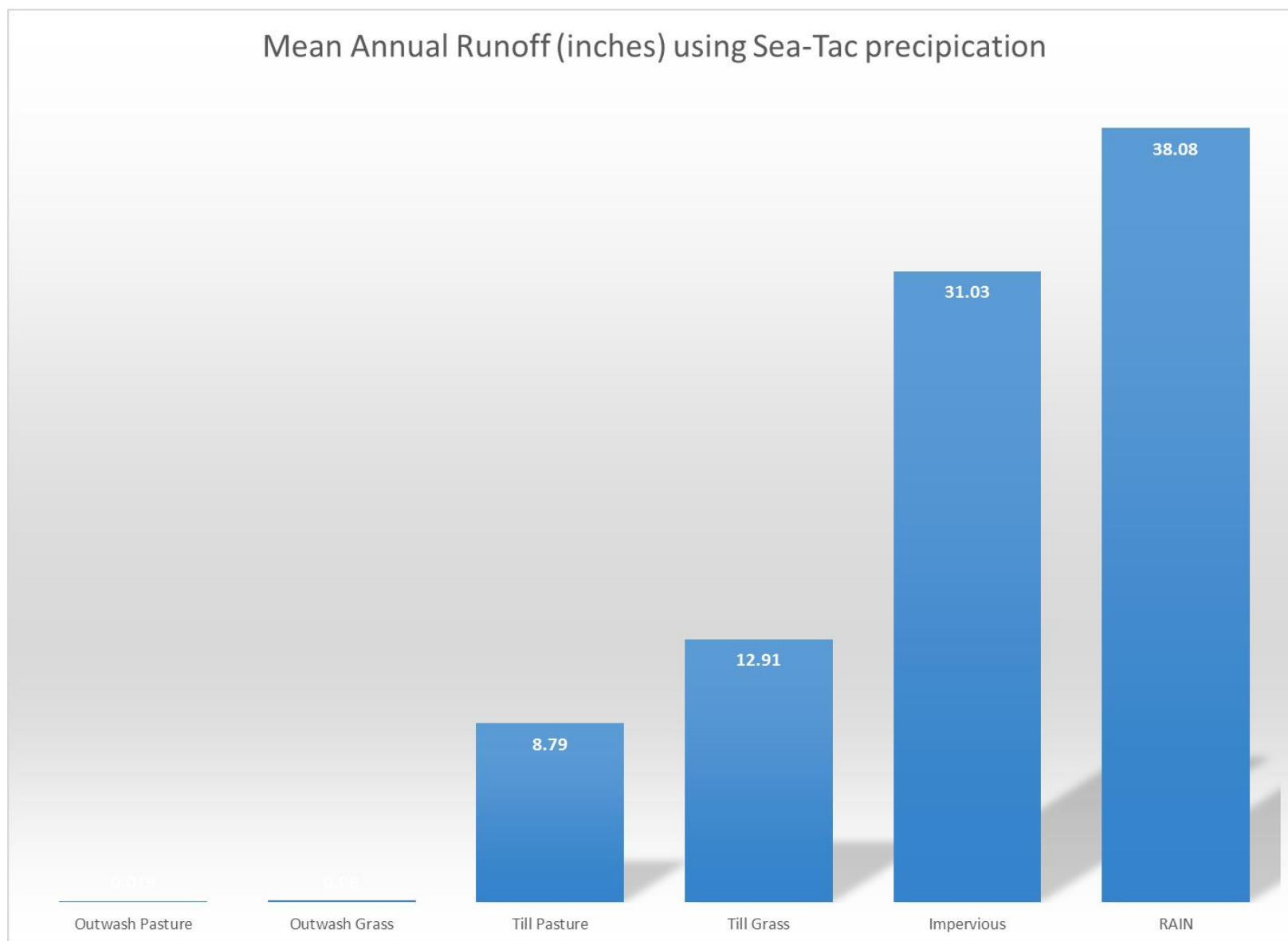


### Legend

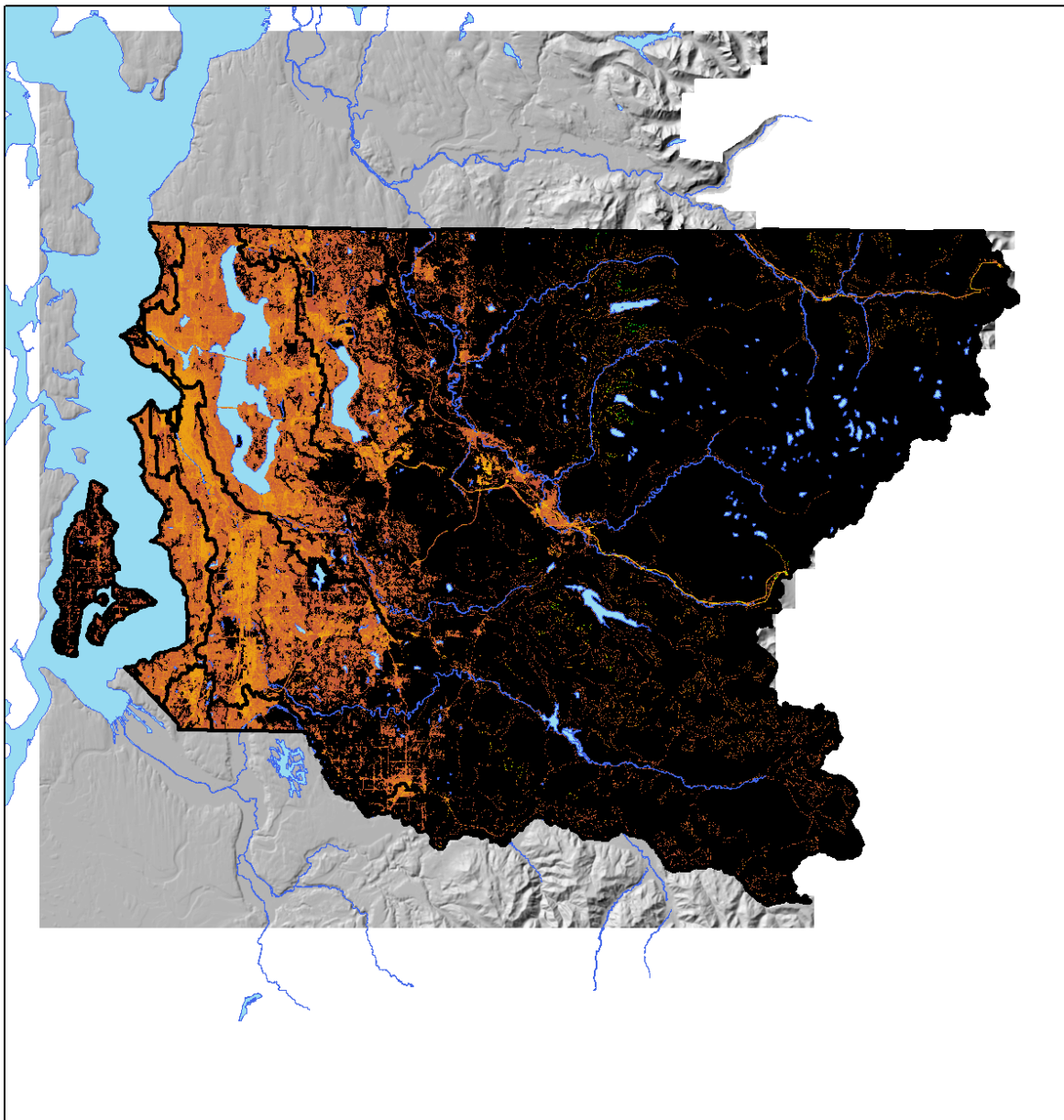
- Roads
- Water Bodies



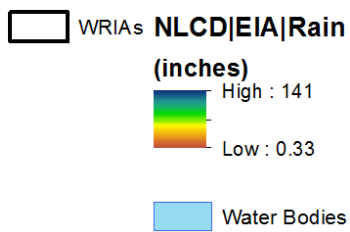
**Figure 11. Road surfaces in King County.**



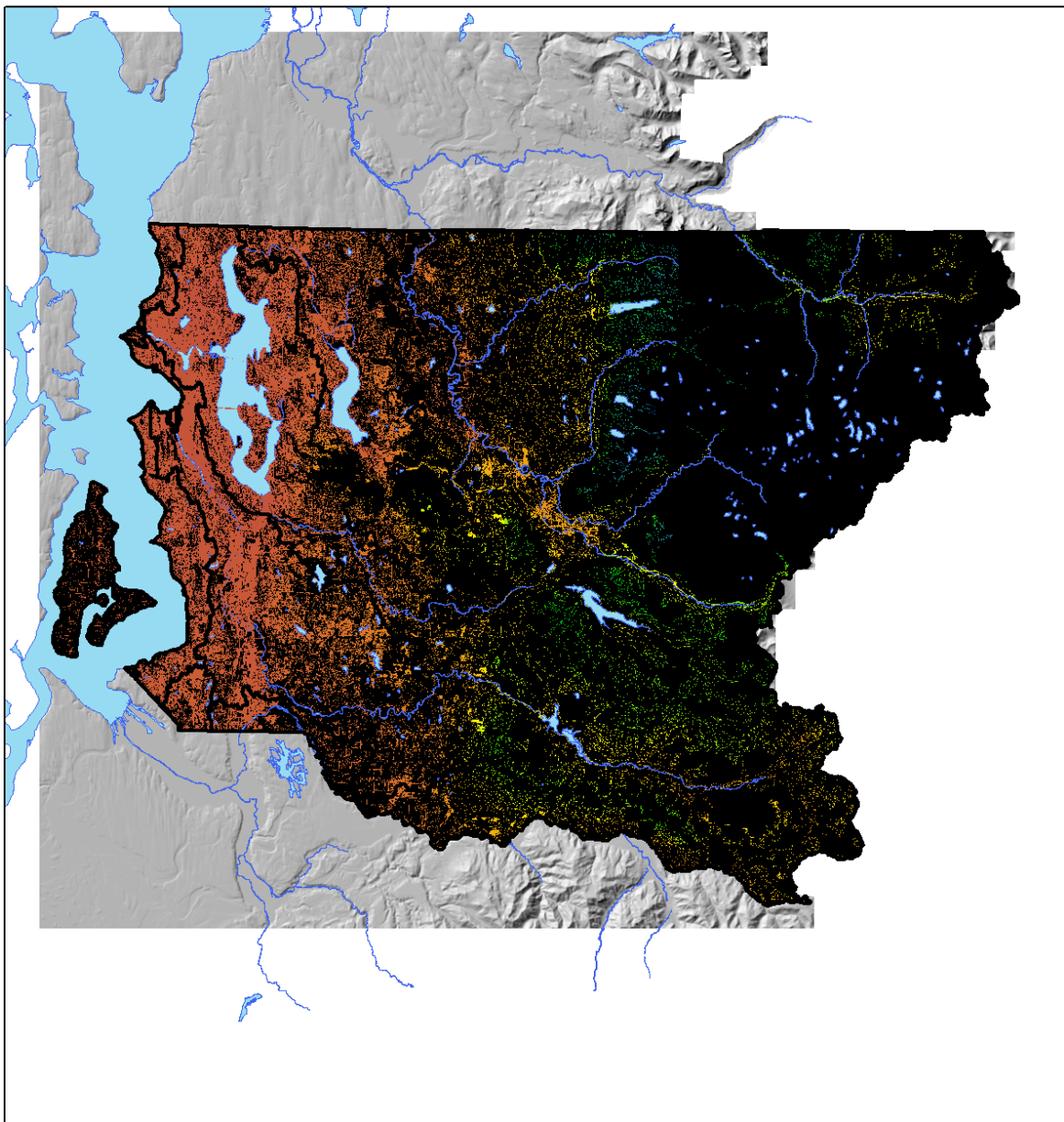
**Figure 12. Mean annual runoff (inches) by HRU representing developed land use using Sea-Tac rainfall.**



**Legend**




**Figure 13. Map of mean annual runoff (inches) using NLCD % Impervious and PRISM rainfall.**





**Legend**

 WRIAs **KC|EIA|Rain**

**(inches)**

 High : 141

 Low : 0.33

 Water Bodies



**Figure 14. Map of mean annual runoff (inches) using King County TIA (x0.81492) and PRISM rainfall.**

**Table 7. King County CSO Facilities (untreated average annual volumes), existing and future conditions.**

Service Area Name	CSOs	Untreated (MGDs)	
		Existing	Future
North	Matthews Park PS	n/a	n/a
	Belvoir PS	0.7355	0.4954
	30th Ave. NE	0.0034	0.0034
	University RS	38.2655	12.1348
	E Pine St.	0.0000	0.0000
	Montlake RS	33.0389	8.8250
	Canal St.	0.3215	0.3369
	Dexter Ave. RS	0.0290	0.0290
	Ballard RS	1.1231	1.3242
	North Beach PS Inlet	0.1411	0.1411
	North Beach PS Wet Well	2.1369	0.9692
Ship Canal Project	11th Ave. NW	13.3485	2.1824
	3rd Ave. W	15.6747	2.9258
Henderson	Henderson St. PS	0.0000	0.0000
	MLK Jr. Way	0.0000	0.0000
	Norfolk St.	0.0302	0.0302
	E Marginal Way PS	0.0000	0.0000
Georgetown	S Michigan St. RS	44.0000	2.3282
	Brandon St. RS	33.4569	0.8185
West Duwamish	8th Ave. S	0.4624	0.4624
	West Marginal PS	0.0000	0.0000
	W Michigan St.	1.3013	0.8123
	Terminal 115	0.7152	0.3188
	Harbor Ave. RS	0.1099	0.0788
	W Duwamish	0.1691	0.1691
	E Duwamish	0.0347	0.0347
Alki	53rd Ave. SW PS	0.5694	0.5694
	63rd Ave. SW	2.4890	2.4890
	SW Alaska St.	0.6380	0.6380
	Murray St. PS & Storage	1.2819	1.2819
	Barton St. PS	0.5199	0.3565
Rainier	Rainier Ave. PS	0.0000	0.0000
	Bayview North	0.2624	0.2624
	Bayview South	0.1317	0.1317
	Hanford At Rainier	1.6141	1.6141
CHLKK	Hanford #1 (Horseshoe)	0.0000	0.0000
	Chelan Hanford#2 Lander Kingdome King RS	329.7657	10.8201
Denny/Interbay	Denny RS & Interbay Weir	2.9570	1.8185
	S Magnolia	2.3458	2.3458
King County CSOs	King County Totals	527.7	56.7

**Table 8. City of Seattle CSO Facilities (untreated average annual volumes), existing and future conditions. Note: not all of Seattle CSOs were available for inclusion in this analysis.**

Service Area Name	CSOs	Untreated (MGs)	
		Existing	Future
Windermere/NUB	SPU 12	0.0003	0.0003
	SPU 13	0.7508	0.7268
	SPU 14	0.0000	0.0000
	SPU 15	0.1327	0.1178
	SPU 18A	0.0022	0.0022
	SPU 18B	1.2804	1.2804
Leschi	SPU 28	0.0277	0.0128
	SPU 29	0.0010	0.0010
	SPU 30	0.0137	0.0137
	SPU 31	0.4300	0.3610
	SPU 32A	0.0683	0.0683
	SPU 34	0.0334	0.0105
	SPU 35	0.0027	0.0027
	SPU 36	0.0004	0.0004
Ship Canal Project	SPU 147A	9.0149	0.6044
	SPU 147B	0.1223	n/a
	SPU 174	4.6629	0.4849
	SPU 150/151	1.8517	0.2330
	SPU 152	34.6998	1.6372
Henderson	SPU 44	0.1221	0.1221
	SPU 45	0.0087	0.0087
	SPU 46	0.1221	0.1221
	SPU 47B	0.3633	0.3349
	SPU 47C	2.3480	2.0813
	SPU 49	1.4852	1.0737
	SPU 171	0.1285	0.1197
Genesee	SPU 38	1.2898	0.7602
	SPU 40	1.3537	0.6584
	SPU 42	0.0916	0.0832
	SPU 43	0.5571	0.4014
	SPU 165	0.0414	0.0311
Delridge	SPU 168	0.7161	0.7161
	SPU 169	0.4244	0.4244
	SPU 99	0.8436	0.5520

**Table 8 (cont.). City of Seattle CSO Facilities (untreated average annual volumes), existing and future conditions. Note: not all of Seattle CSOs were available for inclusion in this analysis.**

Service Area Name	CSOs	Untreated (MGs)	
		Existing	Future
Along EBI	SPU 111A2	0.0226	0.0226
	SPU 111C2	0.0424	0.0358
	SPU 111D	0.0125	0.0125
	SPU 111G	0.0220	0.0220
	SPU 111H	0.0872	0.0872
	SPU 107	0.0075	0.0075
	SPU 72 (Washington)	0.0113	0.0113
	SPU 71 (Madison)	0.0807	0.0471
	SPU 70 (University)	0.0516	0.0424
	SPU 69 (Vine)	2.1258	0.4203
City of Seattle CSOs	City of Seattle Totals	65.5	13.8

**Table 9. King County WTD Treatment Facilities, average annual volume (millions of gallons) of treated stormwater in the combined storm-sewer system for existing and future conditions,**

Treatment Type	Location(s)	Treated (MGs)	
		Existing	Future
CSO Treatment	Carkeek	26.5	26.5
CSO Treatment	Elliott West	184.8	186.5
CSO Treatment	Alki	32.3	32.5
CSO Treatment	MLK Tunnel	8.1	8.1
CSO Treatment	Georgetown	n/a	74.3
CSO Treatment	Chelan Hanford Lander Kingdome King (CHLKK)	n/a	321.4
Secondary Treatment	Allentown (Storm Flow Only)	1201.9	1202.7
Secondary Treatment	West Point (Storm Flow Only)	10953.9	11078.9
King County Facilities	Total Treated Stormwater	12407.6	12931.0